FORTY YEARS OF PRESCRIBED BURNING ON THE SANTEE FIRE PLOTS: EFFECTS ON OVERSTORY AND MIDSTORY VEGETATION

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Abstract—Several combinations of season and frequency of burning were applied in Coastal Plain loblolly pine (Pinus taeda L.) stands over a 40-year period. Pine growth was unaffected by treatment. Above-ground portions of small hardwoods (less than 12.5 cm d.b.h.) were killed and replaced by numerous sprouts. With annual summer burning, sprouts were replaced by grasses and forbs. Study results emphasize the resilience of southern forests to low-intensity burning and that frequent burning over a long period is needed to produce significant changes to forest structure and species composition.

INTRODUCTION

It is well established in the literature and in other papers at this symposium that fire has been a major ecological force in the evolution of southern forests. Ecological and meteorological evidence suggest that lightning-caused fires were a major force in creating open pine forests in the Southeast (Komarek 1974). Archeological evidence has established the presence of Paleo-Indians in the region as early as 12,000 years ago (Chapman 1985). The movement of Indian tribes for game and cropland created variable patterns of fire frequency across the landscape, thus producing a mosaic of vegetation types and stand ages (Buckner 1989). Southeastern forests described by the first white settlers of the 1600's and 1700's were often open pine and hardwood stands with grasses underneath. Early writers suggested these open forests owed their existence to frequent burning (Bartram 1791; Harper 1962; Van Lear and Waldrop 1989). Frequent burning continued through the early 1900's, when fire protection policies of the U.S. Department of Agriculture, Forest Service, and cooperating State Forestry agencies attempted to prevent the use of fire. Prescribed burning for fuel reduction gained acceptance in the 1940's and 1950's, but only after a series of wildfires showed the disastrous consequences of fire exclusion (Pyne 1982). As a result, contemporary forests developed with a dense understory and a larger hardwood component.

It can be difficult to appreciate the important role of fire in shaping the species composition and structure of Southeastern forests. The changes fire causes in plant communities can be slow and depend on fire intensity, the season and frequency of burning, and the number of successive fires used. Opportunities to observe changes in vegetative characteristics over long periods are limited. A long-term study by the Southeastern Forest Experiment Station may give an indication of the ecological role fire once played. The experiment, known as the Santee Fire Plot Study, was established in 1946. Various combinations of season and frequency of burning were maintained for over 40 years. Previous papers have compared the effects of these various fire regimes on pine growth, understory vegetation, and soil properties at specific years during the study. This paper discusses changes to the structure and species composition of the overstory and midstory as they occurred over time and relates those changes to presettlement fire frequency and effects. Changes to understory vegetation after 43 years of burning are presented in another paper in these proceedings (White and others *1991*).

DESCRIPTION OF THE STUDY

Study plots are on the Santee Experimental Forest in Berkeley County, SC, and on the Westvaco Woodlands in neighboring Georgetown County. Both areas are on a Pleistocene terrace on the Lower Coastal Plain at 7.5 to 9.0 m above sea level. Soils include a variety of series but are generally described as poorly drained Ultisols of medium to heavy texture (McKee 1982). Soils are considered productive with a site index of 27 to 30 m for loblolly pine at age 50. In 1946, the overstory of both study sites consisted of unmanaged, but well-stocked even-aged stands of loblolly pine. Common midstory species were dogwood (Cornus florida L.), hickory (Carya sp.), southern red oak (Quercus falcata Michx.), post oak (Q. stellata Wangenh.), water oak (Q. nigra L.), and willow oak (Q. phellos L.). The Santee stand was 42 years old when the study was initiated, while the Westvaco stand was 36 years old. Both stands resulted from natural regeneration after logging. No evidence of previous burning was observed.

Six treatment plots, 0.1 ha in size, were established in each of five replications. Three replications are on the Santee Experimental Forest and two are on the Westvaco woodlands. Treatments include: (1) periodic winter burning, (2) periodic *summer burning, (3) biennial summer burning, (4) annual* winter burning, (5) annual summer burning, and (6) an unburned control. All winter burning was done on December 1 or as soon afterward as weather permitted. Summer burning was done on or soon after June 1. Periodic burns were conducted when 25 percent of the understory hardwood stems reached 2.5 cm in diameter at breast height (d.b.h.).

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This prescription resulted in variable burning intervals ranging from 3 to 7 years. Annual burning has not been interrupted since 1946. Biennial summer burning was added to the study in 1951.

To protect the study, burning techniques were selected to ensure low fire intensity. Selection was made at the time of burning based on prevalent fuel and weather conditions. In general, backing fires were used on periodically burned plots that had thick underbrush or when hot and dry weather increased the risk of high-intensity fires. Headfires or strip headfires were used on annually burned plots that had little underbrush or when fuels were too moist to support a backing fire.

OVERSTORY PINES

Loblolly pine remained the dominant overstory species in all study plots from 1946 to the present. However, growth rates may have been affected. The Santee Fire Plots were designed to study effects on understory vegetation with little consideration to tree growth. Detailed records of the number and size of trees were not kept throughout the history of the study. Therefore, comparisons of treatment effects on diameter and height growth were conducted through increment core analysis and stem analysis procedures, respectively. A more detailed description of these methods was given by Waldrop and others (1987).

Basal area per hectare for each burning treatment throughout the study is shown in figure 1. Since records of tree mortality were not kept, figure 1 represents the basal area of only those trees that survived until the time of sampling (1984). Differences in the levels of these curves represent differences in numbers and sizes of trees in treatment plots in 1984, rather than treatment effects. If burning treatments alter tree growth rates, the effect would be shown as

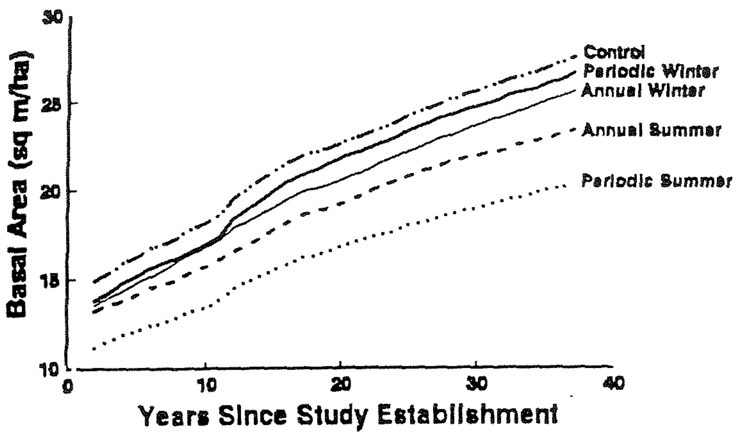

Figure 1.–Cumulative basal area of trees surviving from 1946 through 1984 by burning treatment.

differences in the slopes of these curves rather than differences in the relative heights. All curves in figure 1 are generally parallel, indicating that burning did not affect diameter growth. Basal area increment during each of four 10-year periods was subjected to analysis of covariance, using measured stand basal area to adjust growth rates for stocking effects. These tests indicated that differences between the slopes of lines were not significant for any period (alpha = 0.05).

Mean tree height for each treatment throughout the lives of these stands is shown in figure 2. Curves are very close together, indicating that trees in various treatment plots had similar height growth patterns. During the last 30 years, trees in plots burned annually in winter or summer appear to have slightly reduced height growth. These differences were not significant, however, when compared by analysis of variance (alpha = 0.05).

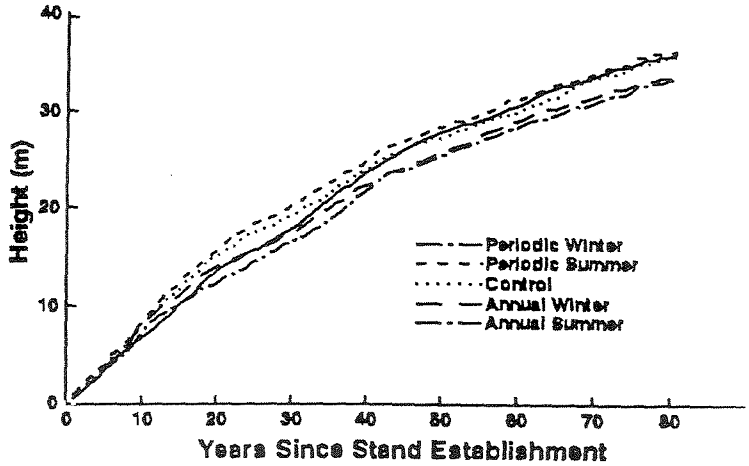

Figure 2.–Mean height of sampled trees by burning treatment from 1905 through 1984.

The lack of differences in diameter and height growth was unexpected. We expected that these low-intensity fires would not cause enough crown damage to reduce growth, and that vegetation control and increased soil fertility resulting from prescribed burning would improve growth. However, overstory pines averaged 40 years old at the beginning of the study and were probably too old to respond by the time these site changes reached meaningful levels. Even though McKee (1982) showed increases in phosphorus and calcium availability, no fertilization studies in the Coastal Plain have shown positive responses to these elements in trees of this age. In addition, soil moisture is rarely limiting to pine growth on these poorly drained Coastal Plain sites, even when competing vegetation is not controlled.

MIDSTORY

Diameter Distribution

Species composition of midstory vegetation changed little since study establishment. Dogwood, hickory, and oaks have remained common on all treatment plots since 1946. However, repeated measurements of the midstory show that diameter distribution of these hardwoods has been changed by the various combinations of season and frequency of burning. The d.b.h. of all hardwoods in all plots was measured at study establishment (1946), at year 20 (1966), and at year 30 (1976). Later descriptions are unavailable due to severe damage from Hurricane Hugo in September 1989. Stem numbers in each of five diameter classes (<2.5 cm, 2.6-7.5 cm, 7.6-12.5 cm, 12.6-17.5 cm, and 17.5+ cm) were used as dependent variables in a split-plot design of an analysis of variance to compare treatment differences over time. Whole-plot effects were those created by burning treatments while the years since study establishment were sub-plot effects. Mean separation was by linear contrast (alpha = 0.05).

At the beginning of the study, unburned control plots appeared to be undisturbed. Every size class of hardwoods from less than 2.5 cm to over 17.5 cm d.b.h. was present (fig. 3A). Diameter distribution followed a reverse-J pattern with numerous stems in small size classes and few stems in larger classes. The number of stems in each size class varied somewhat over time as individual trees grew into larger classes. However, the reverse-J pattern remained.

Hardwood diameter distributions were altered by periodic winter burns and periodic summer burns. For both treatments, the number of stems in the smallest size class (0-2.5 cm) increased significantly between year 0 and year 20 and between year 20 and year 30 (figs. 3B and 3C). Hardwood numbers in the next two classes (2.6-7.5 cm and 7.6-12.5 cm) decreased significantly over the same periods. With periodic summer burning, the smallest size class increased from approximately 11,000 to over 19,000 stems per hectare by year 30. The 2.6- to 7.5-cm size class was most affected, decreasing from over 1,100 to approximately 100 stems per hectare in both periodic treatments. Most changes occurred during the first 20 years, but the changes continued at a reduced rate through year 30.

Hardwoods greater than 12.5 cm d.b.h. were generally unaffected by periodic winter and summer burning (figs. 3B and 3C). At the beginning of the study, these trees were old enough to be protected by thick bark and tall enough that their buds were protected. Most stems less than 12.5 cm d.b.h. were too small to survive burning. However, root systems of these smaller trees survived and produced multiple sprouts, causing the increase in stem numbers in the smallest size class. Burns were frequent enough to prevent the growth of sprouts into a larger size class. Fewer than 10 percent of the trees in the 2.6- to 7.5-cm d.b.h. class survived until year 30. Trees of this intermediate size class are susceptible to top-kill from occasional flareups or hot spots. Since hot spots occur more often during the summer, fewer trees of this size class survived periodic summer burns than periodic winter burns.

Annual winter burning caused changes in the hardwood d.b.h. distribution similar to periodic winter and summer burning. Most stems in the 2.6- to 7.5-cm d.b.h. class were top-killed or girdled during the first few years. Stem numbers in this size class were significantly reduced (from approximately 1,200 per hectare to less than 100) by year 20, with no additional reduction through year 30 (fig. 3D). The number of stems per hectare in the smallest d.b.h. class (0-2.5 cm) increased dramatically over the 30-year period. By year 20, this size class had increased significantly from 16,000 to 21,000 stems per hectare. Between years 20 and 30, that number increased to over 47,000 per hectare. Most of these stems were sprouts less than 1 m tall. Since annual winter burns allow sprouts a full growing season to recover from fire, many root systems survived and produced larger numbers of sprouts after each fire. In year 44, White and others (1991) found a slight decrease in the number of stems per hectare in annual winter burn plots and a substantial decrease in cover by woody plants. Even though sprouts are still numerous, these decreases may indicate declining sprout vigor.

Annual summer burning has nearly eliminated woody vegetation in the 0- to 2.5-cm d.b.h. class (fig. 3E). Root systems were probably weakened by burning during the growing season when carbohydrate reserves were low. Burning was frequent enough to kill root systems of all hardwoods less than 7.5 cm d.b.h. during the first 20 years. A few hardwood seedlings appeared each spring but did not survive the next fire. As with other treatments, the number of stems between 2.6 and 12.5 cm d.b.h. was significantly reduced by annual summer burning and the majority of the change occurred during the first 20 years. Stem numbers of hardwoods over 12.5 cm d.b.h. were unaffected by annual summer burning.

Root Mortality

Patterns of hardwood rootstock mortality observed during the first few years on the Santee Fire Plots prompted investigators to expand the study. In 1951, biennial summer burning was added to provide a comparison with annual summer burning to study root system survival for four hardwood species (Langdon 1981). Individual trees were observed repeatedly to

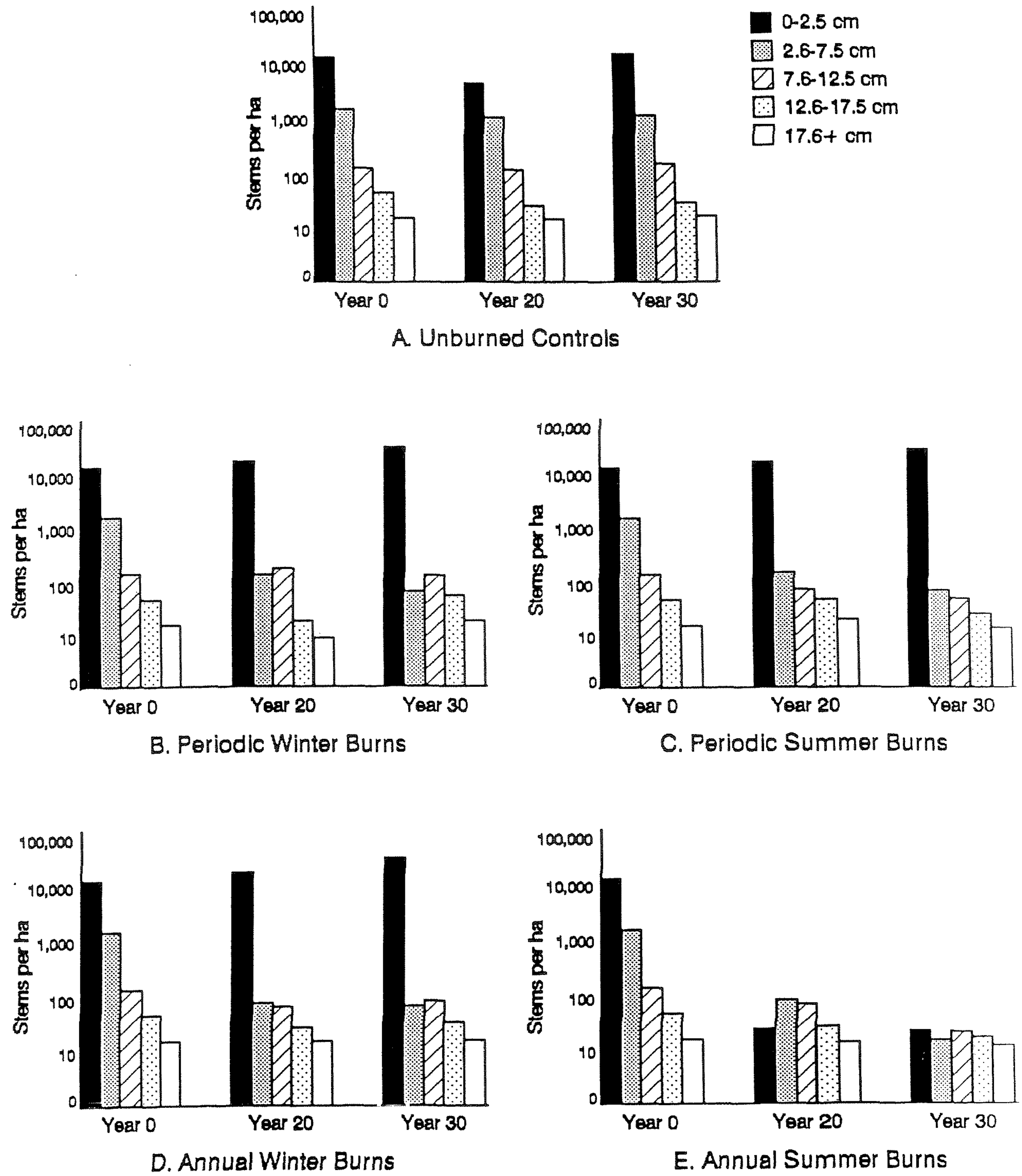

Figure 3.--Diameter distribution of all hardwoods at selected years for (a) unburned control plots, (b) period winter burn plots, (c) periodic summer burn plots, (d) annual winter burn plots, and (e) annual summer burn plots.

determine the number of burns required to kill their root systems. With annual summer burning (fig. 4A), mortality was rapid for sweetgum (Liquidambar styraciflua L.) and waxmyrtle (Myrica cerifera L.), nearing 100 percent within 8 years. Oaks and blackgum (Nyssa sylvatica Marsh.) were more difficult to kill, requiring approximately 20 years to reach 100 percent mortality. Biennial summer burning (fig. 4B) was less effective in killing root systems of all species tested. After 26 years (13 burns), mortality among the oak species remained less than 50 percent. With biennial burning, root systems have an entire growing season to recover.

Apparently, that time is sufficient for carbohydrate reserves to accumulate enough to allow some resistance to fire.

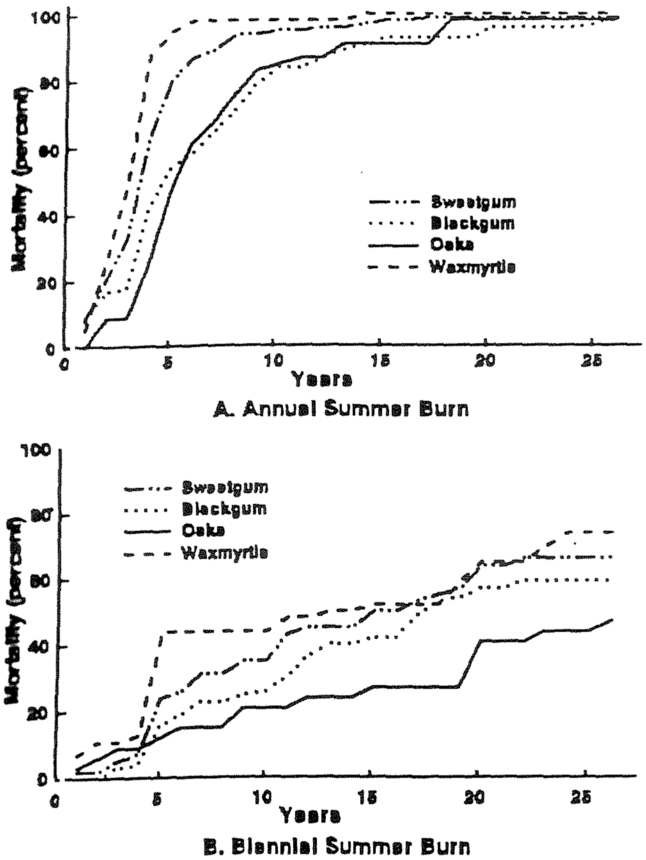

Figure 4.–Cumulative mortality of hardwood roots over 26 years of (a) annual summer burning and (b) biennial summer burning (Langdon 1981).

Species Composition

Survival of hardwoods over 12.5 cm d.b.h. was unaffected by burning treatments and, therefore, changes in species composition among larger trees were not observed. The major effect of burning treatments was to kill the aboveground portion of stems smaller than 12.5 cm d.b.h. With most burning treatments, however, root systems survived and sprouted. If burning was stopped or delayed, sprouts would eventually grow into the midstory producing a stand with species similar to unburned controls. Variations among species in plants' abilities to regenerate after fire created changes in the species composition of regeneration (fig. 5). In year 44, control plots were covered mostly by shrubs with some grasses and hardwoods (White and others 1991). Total coverage was increased by periodic winter and summer burns due to increased sprouting of hardwoods and shrubs. Total coverage after annual winter burns was greater than in control plots, but species composition had changed. Burning greatly reduced the shrub component, which was replaced by grasses and forbs. However, numerous hardwood sprouts remained. Annual summer burning was the only treatment which eliminated regeneration of hardwoods. In these plots, the shrubs and hardwoods that were dominant in 1946 were replaced entirely by grasses and forbs.

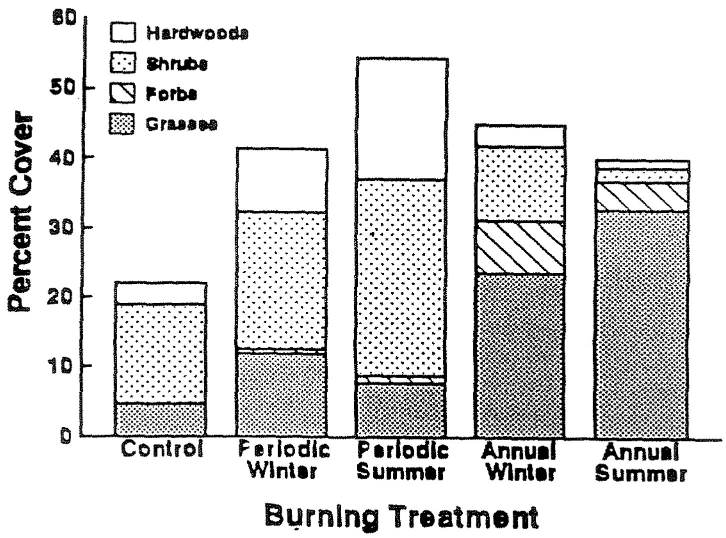

Figure 5.–Percent crown coverage of all understory plants after 44 years of prescribed burning (White and others 1991).

DISCUSSION AND CONCLUSIONS

All tree species on the Santee Fire Plots were well adapted to frequent low-intensity burning. Thick bark and high crowns protected the pines from damage and no growth loss was detected. Hardwoods over 12.5 cm d.b.h. were protected by thick bark and most survived. During the first few years of the study, most hardwoods below 12.5 cm d.b.h. were either top killed or girdled, particularly by summer burning. However, root systems survived and produced multiple sprouts. Annual summer burning over a 20-year period was the only treatment that eliminated hardwood sprouts.

The response of tree species to these long-term prescribed burning treatments was considered minimal. Only one major trend was observed. Small hardwoods were replaced by large numbers of sprouts during the early years of the study. Later, those sprouts were replaced by grasses and forbs. The gradual change from small hardwoods to grasses and forbs was completed by only the most intensive treatment, annual summer burning. White and others (1991) provide evidence that sprout vigor is decreased by annual winter burning, suggesting that these sprouts may eventually be eliminated. However, a large regeneration pool of hardwoods still exists after 44 years of treatment. Periodic burns did little to reduce numbers or vigor of hardwood sprouts.

Hardwood sprout survival was affected by the season and frequency of burning (Langdon 1981). Hot summer fires conducted each year when carbohydrate reserves are low produced relatively rapid (20 years) mortality of hardwood rootstocks. Periodic winter, periodic summer, and annual winter burning allow at least one growing season for sprouts to store carbohydrate reserves in root systems and, therefore, resist mortality. Without annual summer fires, it is questionable whether hardwood sprouts can be eliminated by fire.

This study emphasizes that frequent fires over long periods are needed to create and maintain the open character of pine forests described by early explorers in the Southeast. Periodic burning over 40 years did little to eliminate hardwoods and supported a dense understory shrub layer. Annual winter burns maintain an open understory with vegetation generally less than 1 m tall. However, that understory includes numerous woody sprouts and a dense hardwood midstory would return if burning was delayed a few years. Of all treatments tested, only annual summer burns produced an open understory with no hardwood regeneration. However, presettlement forests did not support the midstory hardwoods present in study plots. In addition to frequent low-intensity fires, an occasional high-intensity fire or other disturbance would eliminate large hardwoods.

Although the Santee Fire Plot Study provides information on the frequency and number of fires required to create and maintain open pine forests, differences exist between its controlled experimental conditions and the environment of presettlement fires. Annual fires set by Indians were controlled only by weather and geographic barriers. Therefore, fire intensity was probably higher than in the Santee study. Also, large herds of deer (Odocoileus virginianus) browsed the open forests and grasslands. Hotter fires and intense browsing would cause higher mortality rates of hardwood sprouts. The Santee Fire Plots were dominated by loblolly pine, which was much less common than longleaf pine (Pinus palustris Mill.) prior to the 20th century. Since loblolly pine seedlings are susceptible to fire, pine regeneration is unlikely to escape the frequent fires on study plots. Seedlings of longleaf pine are resistant to fire during the grass stage. Prior to the 20th century, longleaf pine seedlings probably escaped to form the overstory during short gaps in fire frequency or in localized areas where fire intensity was low.

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